ONTARIO. WATER RESOURCES COMMISSION

Selection of a chemical treatment process for the Lake Timiskaming water supply system.

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SELECTION OF A CHEMICAL TREATMENT PROCE$S

FOR THE

LAKE TIMISKAMING WATER SUPPLY SYSTEM

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DIVISION OF RESEARCH

ONTARIO WATER RESOURCES COMMISSION

1966

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SUMMARY AND CONCLUSIONS

An extensive study was undertaken to find a suitable method of purifying Lake Timiskaming water. This consisted primarily of laboratory tests conducted at the Haileybury waterworks on samples of chlorinated water. These tests were directed towards the clarification of highly coloured soft waters utilizing various water treatment techniques such as diatomite filtration, adsorption with activated carbon and chemical coagulation.

Chemical coagulation was found to be the most practical method of treatment. Therefore extensive jar tests were carried out to determine the effectiveness and the problems associated with the use of alum and iron coagulants in the coagulation of Lake Timiskaming water. The problems related to aggressive waters and coagulation difficulties in cold waters were also considered.

The usefulness of other chemicals such as activated silica, bentonite clay, lime, soda ash and sodium aluminate as coagulant aids was evaluated. Polyelectrolyte type of coagulant aids such as Nalcolyte 110 and Separan NP-10 were also tested.

A brief discussion on the comparative merits of using alum or ferric sulphate for chemical treatment of Lake Timiskaming water is also included.

As a result of reviewing the test data obtained during this investigation, these were some of the principal findings:

(1) The colour in Lake Timiskaming water was found to be as high as 90 Hazen units, of which 80 to 85 units

represented "true colour". A large portion of this high colour was attributable to the presence of unusually high iron concentrations in the water. Lignin substances and tannic acids detected by laboratory analysis were also partially responsible for the colour.

(2) The colour in this water cannot be removed mechanically by simple filtration. Treatment with powdered activated carbon utilizing dosages up to 60 ppm in two stages and a 30 minute contact period prior to filtration had only limited effects. The colour was reduced from a level of 85 to 90 Hazen units to a lower limit of about 40 units.

(3) The clarification of Lake Timiskaming water can be best accomplished by chemical coagulation utilizing either alum or ferric sulphate in conjunction with an appropriate dosage of coagulant aid. Even without coagulant aids, reasonably good flocculation was obtained in cold waters at temperatures in the range of 35 to 38°F when treated with either coagulant not exceeding a dosage of 40 ppm.

(4) Under jar test conditions, ferric sulphate was found to produce significantly better flocculation and clarification than alum. The floc particles yielded by ferric sulphate were very much heavier and faster settling. One of its major drawbacks was the fact that its cost is more than double the price of alum.

(5) Ferric sulphate appeared to be the only iron coagulant which was capable of producing satisfactory flocculation and clarification in this water. Others, such as ferrous sulphate (copperas), chlorinated copperas and ferric chloride were found to be unsatisfactory.

(6) The performance of both alum and ferric sulphate was greatly enhanced by the proper application of coagulant aids. The most effective coagulant aids were found to be activated silica and Separan NP-10. They helped to improve the clarity in the supernatant by producing larger and faster settling floc particles. However, it was noted that whenever dosages in excess of the optimum were added, they had disruptive effects on flocculation and therefore clarity of the supernatant became impaired. Other coagulant aids, such as bentonite clay, soda ash and sodium aluminate were very effective in producing acceptable clarity in the supernatant, but their rate of flocculation was found to be very slow especially in cold water. The latter two chemicals were found to be very effective only if they were added to the samples in discreet amounts before the primary coagulants. With the use of Nalcolyte 110, the flocculation occurred very rapidly with the formation of huge floc particles, but the clarity in the supernatant was not considered to be satisfactory.

(7) Some extremely good results in flocculation were observed in the tests where ferric sulphate was utilized as a coagulant in conjunction with calcium hydroxide (lime).

(8) In jar tests, where lime was added prior to or together with alum or ferric sulphate, poor flocculation and inadequate clarification were noted.

(9) The addition of sludge to the samples had some beneficial effects on flocculation and clarification with alum in the jar tests, but it did not work as effectively in the tests with ferric sulphate.

(10) Because of its inherent characteristics, Lake Timiskaming water is very aggressive. Unless some corrective action is taken to stabilize the water after treatment, serious corrosion problems can be expected to develop in this water supply system. Perhaps one of the most effective methods for this purpose is the judicious application of calcium oxide or calcium hydroxide.

(11) The results of the chlorine demand test indicated that Lake Timiskaming water has a considerable amount of organic matter and other oxidizable substances. The demand of this water at a temperature of 49°F was determined to be approximately 2.5 to 3.0 ppm chlorine after a contact period of 60 minutes.

INTRODUCTION

In an engineering report prepared recently by Canadian Mitchell Associates Limited and entitled "Regional Water Supply Requirements, Township of Bucke", it was recommended that the water for the Townsite of North Cobalt should be supplied from an extension of Haileybury water supply system. Under this proposal, the existing waterworks at Haileybury would have to be modernized with the construction and the installation of new treatment facilities to purify water from Lake Timiskaming. Its capacity would also have to be increased sufficiently to serve the peak domestic demands of both municipalities and to provide for the needs of any future population growths that may take place within that surrounding area.

The water in Lake Timiskaming is highly coloured and very soft. Because of this, some difficulties are usually experienced with chemical coagulation in waters of this nature, especially under conditions of very low temperatures. After treatment, the water becomes very corrosive and additional steps must be taken to protect the distribution system from the ravages of corrosion.

In order to assess more accurately any potential problems involved in the treatment of Lake Timiskaming water, an investigation was carried out by the staff of Ontario Water Resources Commission (OWRC).

PURPOSE OF INVESTIGATION

The primary purpose of this investigation was to collect sufficient data from field and laboratory tests in order to select the proper treatment process which could be incorporated into the design of the new waterworks at Haileybury.

SCOPE

Colour, as found in northern waters is due to the presence of organic acids and other materials leached from decayed vegetation and swamps. It is usually harmless in potable water supplies. However, some consumers may object to highly coloured water from the standpoint of its aesthetic quality and unattractive appearance.

For this reason, main considerations were given to practical methods of treatment which would be capable of reducing the colour levels in the treated water to 15 colour units or less as specified in the OWRC Drinking Water Objectives (1964). With this in mind, the tests were conducted to consider the following methods of colour removal in potable water supplies:

a) diatomite filtration
b) carbon treatment followed by diatomite filtration
c) alum coagulation with selected coagulant aids
d) coagulation with iron salts and selected coagulant aids
e) coagulation utilizing sludge as a coagulant aid.

EXPERIMENTAL DETAILS

Test Conditions

In order to obtain a more realistic appraisal of the problems that may be encountered in the purification processes, it was decided that these tests should be carried out on the samples of Lake Timiskaming water and the various methods of treatment evaluated under the severest possible conditions. Since it has been established that the present water system at Haileybury would be developed to provide treated water to the Lake Timiskaming water supply system, the waterworks at Haileybury was chosen as a logical site for these tests.

Preliminary experiments were conducted at the Haileybury waterworks during the week of October 24 to 28, 1966. These consisted of bench tests involving the application of carbon treatment, diatomite filtration and chemical coagulation to the removal of colour in potable water supplies. The details of these tests are presented on the following pages and the results are tabulated in the Appendix.

Another series of coagulation tests was carried out at the site during the week of November 28 to December 2, 1966 to study the effects of freezing temperatures on chemical coagulation and also to confirm some of the data obtained from previous tests. During the latter period, winter conditions prevailed. The outdoor temperatures had dropped at one point to as low as $-10^{\circ}F$ and a large area of Lake Timiskaming was covered with a thin layer of ice. The water temperatures in the lake were found to be in the range of 36 to $38^{\circ}F$. In order to obtain data under simulated winter conditions, all of the jar tests were performed with samples of water placed in a water bath containing ice and snow so that the variations in temperatures could be kept to a minimum during the entire test.

Diatomite Filtration

In order to evaluate the effectiveness of filtration on the removal of colour, samples of untreated Lake Timiskaming water were filtered through a layer of filter cake supported by a fine grade of filter paper (Whatman No. 3) placed in a Buchner funnel. The filter cake was made up of diatomite filter aid (Celite 503), a layer of approximately 1/8 inch in thickness. This was similar to filtration taking place in a diatomite filter unit. After filtration, the samples were analyzed for colour. The results are recorded under Test No. 1, Table 2.

Carbon Treatment with Filtration

For carbon treatment, samples of raw water were dosed with varying amounts of powdered activated carbon (Nuchar WA), agitated gently under a multiple stirrer for a period of 30 minutes and then filtered through a diatomite filter cake. To simulate two-stage carbon treatment, the above samples were subjected to a second application of carbon and then filtered. Colour analyses were performed after each filtration. The results are tabulated in Table 2.

Chlorine Demand Test

Predetermined dosages of chlorine in the form of sodium hypochlorite solution were added to the samples of untreated water obtained from Lake Timiskaming. The treated samples were placed in a water bath to maintain constant temperature conditions throughout the test. After one hour of contact, available chlorine residuals were determined by means of an amperometric titrator and the results are reported in Table 3.

Coagulation or Jar Tests

The general purpose of coagulation or jar tests is to determine the optimum dosage of coagulant chemicals required to effect good flocculation which, in turn, will help to remove most of the suspended and colloidal impurities in the raw water prior to filtration. These tests were carried out with a multiple stirrer utilizing the following procedures:

a) start with stirrer at 100 rpm (rapid mix).

b) add predetermined dosages of chemicals and coagulant aids.

c) stir rapidly for 1½ minutes and then decrease the speed of the stirrer to 25 rpm (slow mixing).

d) after 20 minutes, stop the stirrer.

e) remove the samples from beneath the paddles and leave them undisturbed for not less than 30 minutes.

f) decant the supernatant or filter.

g) analyze for colour and turbidity.

The coagulant aids were generally added with the main coagulant during the rapid mix. However, in some instances, it was necessary to make slight changes to these procedures. In a few experiments, coagulant aids were added at 30 seconds prior to the main coagulant and in others, they were applied at various time intervals during the flocculation period.

Frequent observations were made on the samples during the jar tests to determine the type of floc produced and the clarity in the settled water. These results were graded according to the modified version of the Willicomb's Floc Index.

WILLCOMB'S FLOC INDEX FOR JAR TESTS *

Index No.	Description of Floc	Settled Water
0	no floc	very hazy
2	pin-point	hazy
4	very small, distinct and uniformly distributed	clear
6	large and ready to precipitate	good clarity but settling has not been completed
8	large	excellent clarity
10	very large and heavy floc which settles rapidly	clear but ittends to have a slight haze

List of Chemicals

This is a list of some of the chemicals that were evaluated during this investigation.

Coagulants

Alum, ferric chloride, ferric sulphate (Ferri-Floc), ferrous sulphate (copperas), and chlorinated copperas.

Coagulant Aids

activated silica, bentonite clay, calcium hydroxide (lime), Nalcolyte 110, Separan NP-10, soda ash, and sodium aluminate (Alfloc 609).

* Babbitt, H. E. and Doland, J. J., Water Supply Engineering, McGraw-Hill Book Company, Inc. (1955)

Collection of Test Samples

Initially, the samples for these tests were obtained directly from Lake Timiskaming. It was collected at a point approximately 250 ft or so from the shore off the old government dock near the waterworks plant. However, comparative jar tests with chlorinated water taken directly from the forcemain at the Haileybury waterworks did not show any varied results. The chlorine residuals in this water were usually found to be in the range of 0.5 to 1.0 ppm determined by the 15-minute ortho-tolidine tests. Since it was being drawn in through the intake pipe extending out into the lake, this water was thought to be more representative of the type of water that would be treated in the new waterworks plant proposed for this project. Therefore all of the subsequent jar tests were conducted on chlorinated water samples.

Coagulation Tests Utilizing Sludge as a Coagulant Aid

Some experiments were conducted in which a slurry of sludge had been added to the samples of raw water prior to the application of the coagulants. The sludge for these tests was collected from previous jar tests in a large flask and after a period of settling, it was concentrated by drawing off a portion of the supernatant liquid by decantation.

At the start of each series of jar tests, it was mixed gently into a homogeneous slurry and then transferred in equal volumes to the samples of raw water before the application of chemicals. From thence the jar tests were carried out in the usual manner.

Calcium Carbonate Stability or Marble Test *

The purpose of the stability test is to determine whether or not a particular sample of water possessed inherent corrosive or scale-forming properties.

In this test, a sample of water is saturated with calcium carbonate by placing in contact with powdered $CaCO_3$ and then the resultant pH and alkalinity values are compared with those of a similar sample not saturated.

* Riehl, M. L., Hoover's Water Supply and Treatment Bulletin 211, 9th Edition, National Lime Association (1962).

DISCUSSION OF RESULTS

Raw Water Quality

Table 1 shows the summary of data related to the chemical quality of the raw water from Lake Timiskaming. These data were compiled from the laboratory reports of the samples collected at Haileybury for the period extending from 1958 to 1966 inclusive.

The water in Lake Timiskaming is typical of those found in the northern regions of Ontario. It is very soft in character with a low alkalinity and dissolved mineral content. Although it is said to be relatively free of any turbidity, the water is frequently highly coloured. The hardness in the water ranges from a low value of 20 ppm to a high of 80 ppm, with the average in the range of 30 to 35 ppm. The colour has been found to be as high as 90 Hazen units, of which 80 to 85 units represented "true colour" and the average was estimated to be about 50 units.

The colour of water is commonly caused by the presence of organic matter leached from the decayed vegetation in the forest and the swamps. The colouring material is said to be composed of humus and tannic acid compounds which impart the yellowish brown tea colour to the surface waters. Laboratory analyses on a recent sample of Lake Timiskaming water revealed the presence of 0.7 ppm tannins and 2 ppm lignins determined as tannic acid. In spite of this, it is believed that the high colour in the lake water during this investigation was attributable to the presence of organic compounds chelated with ferrous iron.* This was substantiated by chemical analyses which revealed unusually high iron content in the water. Laboratory analyses on samples collected from the lake during these two test periods

*Black, A. P. & Willems, D. G., Electrophoretic Studies of Coagulation for Removal of Organic Colour. J.A.W.W.A. Vol.53, p. 589 (May 1961)

indicated iron concentrations of 0.99 ppm and 2.83 ppm respectively.

Recent analyses have also indicated that this water contains organic nitrogen in the range of 0.33 and 1.70 ppm and free ammonia nitrogen in the range of 0.13 and 0.16. For this reason, the chlorine demand in this water was found to be fairly high at some point between 2.5 and 3.0 ppm after a contact period of one hour. The results of the chlorine demand test are tabulated in Table 3.

Highly coloured waters have relatively low pH values of approximately pH 7 and they also tend to be aggressive in nature. This was confirmed by the results of the calcium carbonate stability or the "marble" test in which a sample of raw water was found to be undersaturated with respect to calcium carbonate. This suggested that it was highly corrosive.

The results of the "marble" test were as follows:

	Before	After
Total Alkalinity	29	40
pH	7.20	8.32

The corrosive character of this water was further substantiated by the determination of Langelier's Saturation Index from the water analysis data. The interpretation of these data will be given below.

Diatomite Filtration and Carbon Treatment

The colour in the raw water was determined to be in the range of 80 to 90 Hazen units. With diatomite filtration, it was possible to reduce this to 60 units. Treatment with heavy dosages of carbon decreased the level

further to 40 units. Although the carbon treatment in two stages seemed to be slightly more effective, it was found that the colour level could not be reduced below 40 Hazen units even with dosages up to 60 ppm.

Experiences at existing diatomite filter installations located at paper mills in Iroquois Falls and Timiskaming, P. Q. show that this method of treatment is ineffective for the removal of colour in this type of soft highly coloured water as found in the northern regions of Ontario.

Coagulation Tests

Initial jar tests were conducted to determine the minimum dosages of alum and ferric sulphate required to produce satisfactory coagulation in Lake Timiskaming water for subsequent tests with coagulant aids. The results of these tests are summarized in Table 4.

Tests 1 - 5, Table 4 indicated a minimum alum dosage requirement of 30 to 40 ppm for a satisfactory floc formation. However, even at higher dosages, alum did not produce floc particles with desirable characteristics such as those which were capable of settling quickly and bringing about a good clarification.

Tests 6 - 10, Table 4 showed that a minimum dosage of 35 to 40 ppm ferric sulphate was essential for effecting good flocculation and clarification. In comparison to alum, ferric sulphate appeared to react more quickly and yield a heavier floc. However, there was a higher residual colour in the supernatant of the water treated with the latter coagulant due to the suspension of very fine particles of iron hydroxide. Best clarity was observed in Test 9, Table 4 with 40 ppm ferric sulphate.

It was obvious from the review of the test data that a suitable coagulant aid would be needed to improve flocculation and that this water, after treatment with these coagulant chemicals, could have very corrosive tendencies because of the low pH values.

Tests with Coagulant Aids

In Tables 5 and 6, the results of jar tests with coagulant aids are summarized. These tests show the influence of various aids in the coagulation of Lake Timiskaming water treated with a dosage of 40 ppm alum or ferric sulphate. Tests 1 - 5, Table 5 indicated that a slightly better clarity was attained when the soda ash was added prior to the alum even though the floc particle produced did not increase appreciably in size. It was apparent that increased dosages of soda ash as in Tests 3 and 5, Table 5 did not improve colour removal.

The results of experiments with high calcium lime (calcium hydroxide) are recorded in Tests 6 - 10, Table 5. Coagulation was very poor in Tests 6 and 7 when lime was added prior to the alum and a decided improvement was noticed in Tests 8 and 9, Table 5, where lime was added approximately one minute after the start of flocculation. However, in Test 10, Table 5 addition of excess amounts of lime appeared to have some detrimental effects on floc formation, settling and clarification of the sample.

Nalcolyte 110 and Separan NP-10 were two examples of polyelectrolytes selected for trials in Tests 11 - 15, Table 5. Nalcolyte 110 produced very large and fast settling flocs but the clarity in the supernatant of the settled sample was somewhat less satisfactory than produced by

Separan NP-10. Higher doses of Separan NP-10 and Nalcolyte 110 as in Tests 12 and 14 yielded supernatant with an inferior clarity even though larger floc particles were produced. Best clarity and colour removal were observed in Test 15, Table 5 where 5 ppm soda ash and 0.1 ppm Separan NP-10 were added together with 40 ppm alum.

Experimental data related to Tests 1 - 4, Table 6 indicated that the use of soda ash with ferric sulphate did not yield any spectacular results.

Data from jar tests with lime and ferric sulphate in Tests 5 - 13, Table 6 yielded some very interesting results. Poor coagulation results were noticed in Tests 5, 7 and 11, Table 6, in which the lime was added prior to and together with ferric sulphate. However, in Tests 8 - 10, 12 - 13 where lime was added a few minutes after the start of flocculation, large floc particles were formed and unusually good clarification was observed in the settled sample.

The data from jar tests performed under the conditions of low temperatures are tabulated in Tables 7 and 8. In this series of tests, the samples were placed in a water bath to keep the temperature variations to a minimum. The temperature in the water obtained directly from the forcemain was about 38°F and due to the effect of ice and snow in the water bath, it fell as low as 35.9°F during the jar tests. The average working temperature was approximately 37°F. Attempts to conduct tests with water at near freezing temperatures proved to be unsuccessful.

In order to provide more meaningful data, additional analyses were performed and these included turbidity measurements on the supernatant and the colour analyses on filtered supernatant.

Other coagulant aids such as activated silica, bentonite clay and sodium aluminate were evaluated in this series of jar tests. Tests 1 - 4, Table 7 indicated that activated silica in conjunction with alum yielded large and fast settling flocs that resulted in excellent clarification. In Tests 6 - 10, Table 6, clay and Nalcolyte 110 produced very large floc particles but the clarity and colour removal in the supernatant was not as effective as with activated silica although excellent clarity and colour removal were attained by filtration. The results in Tests 12 - 13, Table 7 showed that Separan NP-10 was very effective in the production of large floc particles with a reasonably good clarity in the supernatant though not as good as the results obtained with activated silica.

With ferric sulphate, the coagulant aids which appeared to work most effectively were small dosages of Nalcolyte 110 and Separan NP-10 as illustrated in Tests 4 - 6, Table 8. However, as noted in previous tests, coagulation involving ferric sulphate with a delayed introduction of lime produced reasonably satisfactory results as shown in Tests 9 - 10, Table 8.

Coagulation Tests with Sludge

Experimental data obtained from a series of coagulation tests utilizing settled sludge as a coagulant aid are tabulated in Table 9 and 10. Tests 1 - 6, Table 9 show comparative results of "Floc Formation" and "Supernatant Analysis" between two samples of water similarly treated with 40 ppm alum and an identical dosage of coagulant aid except that a small volume of sludge slurry was added to one of the samples prior to the test. In each case, the addition of sludge appeared to have beneficial effects on

coagulation. Larger and faster settling floc particles were produced and this resulted in a better clarification in the supernatant. Tests 7 - 8 showed the resultant effects of adding increased amounts of sludge. Although large floc particles did produce a superior clarity and better colour removal in the supernatant in Test 8 after settling, the colour was unexpectedly slightly higher after filtration than that in Test 7 where lesser amounts of sludge was added.

Some interesting observations were made in the jar tests carried out with ferric sulphate and sludge. The results of Test 1 - 9, Table 10 indicated that despite the formation of large floc particles, the addition of sludge appeared to have some detrimental effects on the coagulation of the water. With the exception of Tests 10 - 11, Table 10 involving Separan NP-10, the supernatant of the samples treated with sludge exhibited inferior clarification. The effect of solid contact with excess sludge on the clarity of supernatant was demonstrated in Tests 1 - 3, Table 10.

Effects of Low Temperatures

Attempts to carry out jar tests with water temperatures closer to the freezing point proved to be unsuccessful. However, it was felt that the results of these tests conducted in water at the prevailing temperatures of 36 to 38^{o}F might help to provide an insight into coagulation problems that could be encountered at lower temperatures.

It is a well known fact that chemical coagulation in lower water temperatures requires longer flocculating time or even a larger coagulant dosage. During this investigation, it was found possible to obtain some form

of flocculation in colder water with essentially the same minimum dosage of the primary coagulant. However, in the jar tests with alum, the reaction was somewhat slower, smaller flocs were produced and the settling was very much slower, but the clarity in the settled water was unusually good. Similar observations were made in the tests with ferric sulphate except that a greater discoloration was noted in the supernatant of the test samples at lower temperatures. This colour was caused by the suspension of very fine floc consisting of iron hydroxide in the supernatant.

The rate of flocculation and floc settling in the samples at lower temperatures were definitely improved by the use of coagulant aids in conjunction with alum and ferric sulphate. Activated silica was found to be particularly effective for this purpose. Separan NP-10, in extremely small dosages, produced unusually good results. Nalcolyte 110 helped to bring about a speedier flocculation but the clarity in the settled water was slightly hazy. Bentonite clay did not increase the rate of flocculation but it did hasten floc settling and yielded settled water with a satisfactory clarity. The use of lime did not improve alum coagulation but it seemed to work very effectively with ferric sulphate. With the proper application of coagulant aids, it is believed that coagulation problems at lower temperatures can be kept to a minimum.

Experiences with Copperas

Jar tests with copperas or ferrous sulphate were attempted but they did not yield very satisfactory results. For the proper application of copperas, it must be oxidized

first to the ferric form with either lime or chlorine to produce the desired ferric hydroxide floc. Because of the very low values of alkalinity and pH, Lake Timiskaming water did not respond very well to the treatment with copperas and lime. The reaction involving the oxidation of copperas and the subsequent formation of ferric hydroxide floc does not occur when the pH value in the water is less than pH 8.5. For this reason, it is reported that copperas is seldom used in the coagulation of highly coloured water which coagulates best at pH values less than pH 6.

Further tests were carried out with chlorinated copperas; the latter was treated with appropriate dosages of sodium hypochlorite. Better flocculation was observed but the clarity and the colour removal in the treated samples were somewhat disappointing.

Corrosion Problems

With the purification of highly coloured soft waters by means of chemical coagulation, corrosion problems in the water supply system are not uncommon. Therefore, it was necessary to consider the corrosive potential of water after treatment so that some provisions can be made in the design of the water treatment plant for corrosion control.

Corrosion of metals by water is a very complex process influenced by many interdependent variables related to the character of the water and the metal, flow velocity and temperature. For this reason, it is almost impossible to carry out simple laboratory tests from which pertinent data related to the corrosive behaviour of water can be utilized for prescribing an appropriate corrosion inhibitor.

Present methods for determining corrosiveness of water is based on its equilibrium conditions with respect to calcium carbonate. If the water has a tendency to dissolve calcium carbonate, it is said to be undersaturated with respect to calcium carbonate, and therefore it may be corrosive in nature. By means of the "marble" test, it is possible to determine alkalinity and pH which would prevail when the water is in equilibrium or saturated with respect to calcium carbonate. Another method is the application of the calcium carbonate saturation index devised by Langelier and calculated from the water analysis data. Although Langelier's saturation index tends to present an over-simplified picture of the corrosion problems, it indicates the pH value of the water that would be in equilibrium with calcium carbonate.

A negative value of the saturation index means that the water is undersaturated with calcium carbonate and may tend to be corrosive. A positive value indicates the reverse. As a general rule, it can be stated that corrosion problems are not expected in cold waters with an index more positive than -0.5 and in hot waters with a positive index.

Saturation indices for chlorinated Lake Timiskaming water and selected samples from the jar tests are presented in Table 11. Samples treated with alum and ferric sulphate as well as chlorinated water tended to be very corrosive as indicated by their high negative values. It can be seen that a lime dosage of 30 ppm was needed to stabilize the water treated with ferric sulphate under the test conditions. It is believed that a similar dosage of lime would have been required to bring about a carbonate equilibrium in the water coagulated with alum.

Coagulation with Alum or Ferric Sulphate

The results of the laboratory tests have indicated that the purification of Lake Timiskaming water can be best accomplished by chemical coagulation with a judicious application of either alum or ferric sulphate. However, in order to select the most practical treatment process or to decide on which of the two offer the best advantages, it is necessary to consider and compare various aspects such as costs and particular problems related to handling and storage.

Ferric sulphate appears to offer a few definite advantages as a coagulant over alum in the coagulation of Lake Timiskaming water. In the jar tests, it produced floc particles of superior characteristics. The flocs were formed more quickly, heavier, and faster settling. The clarity in the supernatant of settled water coagulated with ferric sulphate was significantly better than that of the water coagulated with alum. It has been reported that better plankton removals were achieved by flocculation with ferric sulphate and therefore longer filter runs were obtainable.

In coagulation with ferric sulphate, it was found that lime could be utilized in a dual role as an effective coagulant aid and as an additive to stabilize the corrosive tendencies in the finished water. This may help to eliminate the need for another chemical to be used as a coagulant aid. This is an advantage over alum coagulation.

One of the major drawbacks, perhaps a significant one when compared to alum, is the relative cost of ferric sulphate as a primary coagulant. Data in Table 12 which gives a summary of approximate costs for various water

treatment chemicals indicate that the cost of ferric sulphate is more than double the price of alum; $43 to $50 per ton for alum vs. $100 to $120 per ton for ferric sulphate.

Another disadvantage of ferric sulphate treatment is the possibility of undesirable discolorations due to residual iron in the finished water caused by poor coagulation. Water produced by this method might be a little more aggressive than that treated with alum.

Alum as a coagulant, has an advantage of producing a colour-free water. Although it is capable of working over a broad pH range, alum yields a light, feathery type of floc in soft waters with low alkalinity without the use of a coagulant aid. The alum floc tend to redissolve at high pH values especially with the application of lime, whereas this does not occur with ferric sulphate. In waters at very low temperatures, alum coagulation proceeds very slowly and with some difficulty.

The dosage requirements of both of these chemicals in the coagulation of Lake Timiskaming water was approximately about 40 ppm. It was noted that floc formation occurred with a lower dosage of alum in the earlier tests when the water temperature was around 50°F.

In addition to the basic price of these chemicals, transportation costs must be considered and incorporated into the cost of treatment. A brief summary of general freight rates by rail between Haileybury and two major cities of Toronto and Montreal is presented in Table 13. It should be noted that liquid alum albeit slightly more expensive than dry alum, can be supplied from Ansonville, Ontario, located approximately 120 miles north of Haileybury, whereas the nearest source of supply for ferric sulphate and other chemicals is almost 300 miles away in Toronto and southern Ontario.

APPENDIX

Table 1 - Raw Water Quality - Lake Timiskaming

Table 2 - Colour Removal by Carbon Treatment and Diatomite Filtration

Table 3 - Results of Chlorine Demand Test

Table 4 - Preliminary Jar Tests

Table 5 - Jar Tests with Alum and Coagulant Aids

Table 6 - Jar Tests with Ferric Sulphate and Coagulant Aids

Table 7 - Jar Tests with Alum and Coagulant Aids

Table 8 - Jar Tests with Ferric Sulphate and Coagulant Aids

Table 9 - 10 - Jar Tests to Show Effects of Sludge on Coagulation

Table 11 - Chemical Analyses of Purified Lake Timiskaming Water

Table 12 - Cost of Water Treatment Chemicals

Table 13 - General Freight Rates

TABLE 1

SUMMARY OF RAW WATER QUALITY - LAKE TIMISKAMING

TOWN OF HAILEYBURY

Chemical Analysis	Maximum		Minimum
Alkalinity, ppm $CaCO_3$	80		6
Apparent Colour, Hazen Units	90		15
Calcium, ppm Ca		12	
Chlorides, ppm Cl^-	40		2
Dissolved Solids, ppm		66	
Hardness, ppm $CaCO_3$	82		22
Iron, ppm Fe	2.4		0.32
Nitrogen, ppm NH_3		0.13 to 0.16	
" , ppm NO_3		0.05 to 0.10	
" , ppm NO_2		0.00	
" , ppm Kjeldahl		0.33 to 1.70	
pH at Lab	8.3		6.1
Saturation Index		-2.2 to-2.33	
Turbidity, Units	47		3.1

With the exception of calcium, dissolved solids, nitrogen and saturation index, all other analyses were compiled from samples collected by OWRC personnel from 1958 to 1966 inclusive. The above mentioned data were obtained from the analyses of two samples collected during the recent investigations in 1966.

TABLE 2

COLOUR REMOVAL BY CARBON TREATMENT AND DIATOMITE FILTRATION

Test No.	Carbon Dosage	Colour of Filtrate
1	0 ppm	50-60 Hazen Units
2	10	50
3	20	50
4	30	50
5	10/10*	40
6	20/20*	40
7	10/50*	40

* The sample was treated with activated carbon in two stages: first, with a dosage of 10 ppm and filtered; and then followed by treatment with a second dosage of 10 ppm.

TABLE 3

RESULTS OF THE CHLORINE DEMAND TEST

Dosage	Chlorine Residual		pH	Chlorine Demand
	Free	Total		
2.00	0.00	0.25	7.75	-
2.25	0.02	0.25		-
2.50	0.04	0.25		-
2.75	0.08	0.34		2.41
3.00	0.14	0.42		2.58
3.25	0.24	0.51		2.74
3.50	0.32	0.62	7.45	2.88

Notes: (1) With the exception of pH, all of the values are reported in ppm.

(2) This test was conducted on the sample of raw water collected on December 1, 1966.

(3) Contact period with chlorine - 60 ± 1 min.

(4) Temperature - 49 ± 1°F.

TABLE 4

SUMMARY OF RESULTS - PRELIMINARY JAR TESTS (1)

Test No.	Coagulant Dosage	Floc Formation			Supernatant Analysis (5)			
	ppm	Time (2)	Floc Index (3)	Settling (4)	M-Alk	Colour	pH	Appearance
1	20 Alum	-	0	-	9	-	6.03	turbid
2	30 Alum	60 sec.	5	very slow	7	15	5.90	sl. hazy
3	40 Alum	45	6	slow	3.5	7.5	5.67	hazy
4	50 Alum	45	6	slow	0	10	4.90	hazy
5	60 Alum	30	8	slow	0	15	4.75	sl. hazy
6	20 Ferric Sulphate	-	0	-	8.0	-	6.16	turbid
7	30 Ferric Sulphate	-	0	-	-	-	5.85	turbid
8	35 Ferric Sulphate	25	5	slow	1.0	40	5.35	hazy
9	40 Ferric Sulphate	10	6	slow	0	25	4.95	clear
10	50 Ferric Sulphate	20	5	slow	-	50	4.00	sl. hazy

Notes: (1) For details on the jar tests, see page 9.

(2) Time for the appearance of first floc particles after the start of slow mixing. If any floc particles were visible in the sample at the start of the slow mixing period, no indications will be made.

(3) Willcomb's Floc Index for Jar Tests, see page 10.

(4) Observations were made during the first five minutes after the termination of slow mixing.

(5) Analyses were performed on the decanted water that has been allowed to settle for at least 30 minutes M-Alk indicates Total Alkalinity by Methyl Orange Indicator Method; Colour represents Apparent Colour in Hazen units and Appearance indicates the degree of clarity; turbid, hazy, slightly hazy, and clear.

(6) Best results were obtained in Tests 3 and 9.

TABLE 5

SUMMARY OF RESULTS - JAR TESTS WITH ALUM (1) AND COAGULANT AIDS

Test No.	Coagulant Aid	Floc Formation			Supernatant Analysis			
	ppm Dosage	Time	Floc Index	Settling	M-Alk	Colour	pH	Appearance
1	none	15 sec	6	slow	2	10	5.65	clear
2	7 Soda Ash (2)	10	6	slow	8	7.5	5.93	clear
3	14 Soda Ash	20	6	slow	13	12.5	6.17	sl. hazy
4	7 Soda Ash	10	6	slow	9	15	6.00	hazy
5	14 Soda Ash	20	6	slow	12	20	6.20	hazy
6	10 Lime (3)	-	2	none	17	-	6.60	turbid
7	20 Lime	-	0	none	27	-	7.60	turbid
8	5 Lime	10	6	fast	13	20	6.80	sl. hazy
9	10 Lime	25	6	fast	16	25	6.70	hazy
10	20 Lime	25	4	very slow	27	45	8.30	hazy
11	0.1 Separan NP-10 (4)	-	6	fast	5	10	5.00	clear
12	0.2 Separan NP-10	-	6	fast	5	7.5	5.00	sl. hazy
13	5 Nalcolyte 110	-	8	rapid	4	7.5	5.45	hazy
14	10 Nalcolyte 110	-	10	rapid	4	15	5.45	hazy
15	5 Soda Ash 0.1 Separan NP-10	-	6	fast	8	5	5.75	sl. hazy

Notes:
(1) In this series of tests, a dosage of 35 ppm alum was added to each sample.
(2) In Tests 2-3, soda ash was added to the samples before alum while in Tests 4-5, it was added one minute after the addition of alum.
(3) In Tests 6-7, lime was added before alum and in Tests 8-10, lime was added one minute after the addition of alum.
(4) Aid was added immediately after the alum in Tests 11-14
(5) In Test 15, soda ash, alum and then Separan NP-10 were all added during the rapid mix.
(6) For the analysis of Test Samples, see data in Table 6.

TABLE 6

SUMMARY OF RESULTS - JAR TESTS WITH FERRIC SULPHATE (1) AND COAGULANT AIDS

Test No.	Coagulant Aid	Floc Formation			Supernatant Analysis			
	ppm Dosage	Time	Floc Index	Settling	M-Alk	Colour	pH	Appearance
1	none	5 sec.	5	very slow	0	25	4.45	slight hazy
2	10 Soda Ash	60	6	slow	3	70	5.70	slight hazy
3	20 Soda Ash	-	0	none	10	-	6.03	turbid
4	10 Soda Ash (1 min) (4)	0	6	slow	4	35	5.80	slight hazy
5	10 Lime	0	0	none	-	-	6.50	turbid
6	10 Lime (1 min)	0	6	fast	13	60	6.60	slight hazy
7	20 Lime	0	2	very slow	19	100+	7.20	turbid
8	20 Lime (1 min)	-	7	fast	19	80	7.30	slight hazy
9	20 Lime (2 min)	-	6	fast	18	80	7.50	slight hazy
10	20 Lime (5 min)	-	8	fast	21	40	8.40	clear
11	40 Lime	-	2	very slow	-	-	10.0	turbid
12	40 Lime (5 min)	-	7	fast	33	70+	9.60	clear
13	50 Lime (5 min)	-	8	fast	49	50	10.50	clear

Note: (1) Dosage of 40 ppm Ferric Sulphate was added to each test sample.

(2) In Tests 2, 3 and 5, the aid was added one minute before ferric sulphate.

(3) In Tests 7 and 11, the aid was together with the coagulant during the rapid mix.

(4) This indicates the time interval after the start of the slow mix when the aid was added.

(5) Analysis of Test Samples (Average Values)

M-Alk - 19 ppm	pH - 6.9	Turbidity - 23 units
Colour - 80 to 85 units	Temperature - 49.5°F	Chlorine Residual - 0.6 ppm

TABLE 7

SUMMARY OF RESULTS - JAR TESTS (1) WITH ALUM (2) AND COAGULANT AIDS

Test No.	Coagulant Aid ppm	Floc Formation Time	Floc Index	Settling	M-Alk	Supernatant Analysis Colour	Colour (Filtered) (3)	pH	Turbidity
1	none	2.5 min	4	very slow	11	25	5	5.90	7.5
2	2.5 Act. Silica	0.5	6	fast	-	5	0	6.30	2.15
3	5. Act. Silica	-	8	fast	11	5*	-	6.10	1.5
4	10 Act. Silica	-	10	rapid	-	5	0	6.25	1.8
5	10 Clay	0.75	5	slow	-	20	5	-	5.3
6	20 Clay	0.75	6	slow	-	15	5*	-	3.4
7	30 Clay	0.75	6	slow	-	15	7.5	-	6.1
8	2.5 Nalcolyte 110	-	8	rapid	-	30	5*	6.10	7.8
9	5 Nalcolyte 110	-	10	rapid	-	20	5*	6.10	10.0
10	2.5 Nalcolyte 110 30 Lime	-	10	rapid	46	30	20	9.52	7.8
11	25 Lime (10 min)	-	6	slow	48	40	25	9.75	7.5
12	0.05 Separan NP-10	1.0	6	slow	-	20	0	6.32	6.1
13	0.1 Separan NP-10	1.0	6	slow	-	15	0	6.47	6.5
14	5 Soda Ash	1.5	6	slow	17	15	10	6.58	5.27
15	10 Soda Ash	1.5	6	slow	20	20	5	6.72	4.5
16	5 Sodium Aluminate	0.5	4	slow	-	-	-	6.43	2.0

* less than

Notes: (1) All the samples in this series of jar tests were placed in a water bath.
(2) Dosage of 40 ppm Alum was added to each sample.
(3) After settling, supernatant was filtered through Schleicher & Schuell Black Ribbon Filter Paper No. 589 and colour analyses are recorded under the heading of "(Filtered)".

Analysis of Test Samples (Average Values)

M-Alk - 29 ppm
Colour - 85 Hazen units
pH - 6.9
Temperature - 36°F
Turbidity - 47 units
Chlorine Residual - 0.5 to 0.6 ppm

(4) In Tests 14-15, soda ash was added before alum.

TABLE 8

SUMMARY OF RESULTS - JAR TESTS (1) WITH FERRIC SULPHATE (2) AND COAGULANT AIDS

Test No.	Coagulant Aid ppm	Floc Formation		Supernatant Analysis				
		Floc Index	Settling	M-Alk	Colour	(Filtered)	pH	Turbidity
1	none	4	very slow	2	50	50	5.25	7.5
2	5 Act. Silica	6	slow	9	70	30	5.90	11.0
3	10 Act. Silica	4	slow	-	65	20	6.05	8.9
4	2.5 Nalcolyte 110	10	rapid	-	50	5	5.50	6.5
5	5 Nalcolyte 110	10	rapid	-	60	17.5	5.70	8.9
6	0.1 Separan NP-10	6	fast	-	45	15	5.70	6.1
7	20 Lime	6	fast	31	80	35	7.90	6.6
8	20 Lime (5 min)	8	rapid	40	70	17.5	8.40	6.1
9	20 Lime (10 min)	6	rapid	31	75	15	7.96	7.4
10	30 Lime (5 min)	6	fast	-	45	10	9.30	4.3
11	50 Lime (5 min)	6	fast	58	60	20	10.10	4.3
12	50 Lime (5 min)	6	fast	55	60	20	10.00	7.4

Notes: (1) All the samples in this series of jar tests were placed in a water bath.

(2) 40 ppm Ferric Sulphate was used in the above tests.

(3) For the analysis of Test Samples, see data in Table 7.

TABLE 9

RESULTS OF JAR TESTS TO SHOW EFFECTS OF SLUDGE ON COAGULATION (1)

Test No.	Coagulant Aid ppm Dosage	Volume of Sludge (2)	Floc Formation		M-Alk	Supernatant Analysis		pH	Turbidity
			Floc Index	Settling		Colour	(Filtered)		
1	-	nil	4	slow	-	30	10	6.05	5.8
2	-	20	5	fast	-	25	5* (2)	6.05	5.2
3	5 Act. Silica	nil	6	fast	-	15	5*	6.10	1.65
4	5 Act. Silica	20	8	very fast	-	7.5	5*	6.20	1.80
5	25 Lime (3)	nil	8	fast	41	65	40	9.20	12.9
6	25 Lime	20	8	rapid	42	35	15	8.70	3.8
7	25 Lime 5 Act. Silica	10	6	fast	-	35	5*	8.60	7.5
8	25 Lime 5 Act. Silica	20	8	rapid	42	25	15	9.30	3.0

Notes: (1) Dosages of 40 ppm Alum were added to each sample placed in a water bath during the test.

(2) * denotes less than 5 Hazen units.

(3) Lime was added five minutes after the start of the slow mix.

(4) For the analysis of the test samples, see data in Table 7.

TABLE 10

RESULTS OF JAR TESTS TO SHOW EFFECTS OF SLUDGE ON COAGULATION (1)

Test No.	Coagulation Aid ppm Dosage	Volume of Sludge (2)	Floc Formation Floc Index	Floc Formation Settling	M-Alk	Supernatant Analysis Colour	Supernatant Analysis (Filtered)	pH	Turbidity
1	-	nil	4	very slow	6	35	10	5.60	4.3
2	-	10 ml.	5	mod. fast	7	85	50	5.80	11.2
3	-	20	6	fast	7	85	40	5.87	10.7
4	10 Act. Silica	nil	4	slow	-	65	20	6.05	8.9
5	10 Act. Silica	10	6	fast	-	120 (2)	85	6.10	22
6	5 Nalcolyte 110	nil	10	rapid	-	60	20	5.71	8.9
7	5 Nalcolyte 110	10	10	rapid	-	85	35	5.85	17
8	2.5 Nalcolyte 110	nil	8	rapid	-	50	5	5.50	6.5
9	2.5 Nalcolyte 110	10	10	rapid	-	100	30	5.80	24
10	0.1 Separan NP-10	nil	6	fast	-	45	15	5.73	6.1
11	0.1 Separan NP-10	10	7	fast	-	30	5 (3)	5.60	3.7

Notes: (1) Dosage of 40 ppm Ferric Sulphate was added to each sample placed in a water bath.

(2) Actual colour measurement was greater than 120 Hazen units.

(3) Less than 5 Hazen units.

(4) For the analysis of the test samples, see data in Table 7.

TABLE 11

CHEMICAL ANALYSES OF LAKE TIMISKAMING WATER AFTER PURIFICATION (1)

	Treatment (2)	Hardness	M-Alk	Iron	pH	Dissolved Solids	Colour	Turbidity	Saturation Index (3)
1.	Chlorination only	40	22	0.99	7.0	66	85	32	-2.33
2.	40 ppm Alum and 10 ppm Lime	46	19	0.10	7.1	68	10	0.7	-2.30
3.	40 ppm Alum and 7.5 ppm Alfloc 609	36	10	0.01	6.6	28	10	0.7	-3.18
4.	40 ppm $Fe_2(SO_4)_3$ and 10 ppm Lime	48	18	0.20	6.8	70	15	2.3	-2.54
5.	40 ppm $Fe_2(SO_4)_3$ and 20 ppm Lime	56	26	0.18	7.2	78	15	1.3	-1.87
6.	Chlorination only	45	29	2.25	7.2	96	90	31	-2.20
7.	40 ppm Alum and 2.5 ppm Silica	44	31	0.08	6.5	66	5*	1.4	-2.68
8.	40 ppm Alum, 2.5 ppm Silica and 25 ppm Lime	68	19	0.20	8.8	118	5*	1.5	-0.50
9.	40 ppm Alum and 25 ppm Lime	70	42	0.49	8.7	132	15	10.0	-0.27
10.	40 ppm $Fe_2(SO_4)_3$	40	7	0.71	5.9	84	5*	2.6	-3.81
11.	40 ppm $Fe_2(SO_4)_3$ and 30 ppm Lime	76	38	0.48	9.0	108	10	1.5	+0.06
12.	40 ppm $Fe_2(SO_4)_3$, 30 ppm Lime and 2.5 ppm Silica	74	37	0.72	9.3	130	5*	1.5	+0.40

Notes: (1) Except for samples Nos. 1 and 6, chemical analyses were performed on the supernatants filtered through S & S No. 589 filter paper.

(2) Samples 1-5 were selected from jar tests conducted during October 24 to 28, 1966 and Samples 6-12 were selected from those carried out during November 28 to December 2, 1966.

(3) Calcium Carbonate Saturation Index (Langelier's Index) calculated from tables in Data Book, compiled by The Permutit Company (1961), p. 106.

TABLE 12

COST OF WATER TREATMENT CHEMICALS

Chemical	Size of Container	Shipping Point	Price
Activated Silica * and Activating Agents			
'N' Sodium Silicate	400 lb drums	Toronto	$3.60 per cwt.
Ammonium Sulphate	100 lb bags	Toronto	$5.25 per cwt.
Sodium Bicarbonate	100 lb bags	Toronto	$5.00 per cwt.
Sulphuric Acid (conc)	carboys	Toronto	$3.80 per cwt.
Alum, granules	100 lb bags	Arvida, P.Q. Valleyfield, P.Q.	$43 per ton
Alum, liquid	20,000 lb (minimum)	Ansonville Ottawa (in 1968)	$52 per ton (dry weight)
Bentonite Clay	100 lb bags	Toronto	$40 to 50 per ton
Ferric Sulphate	100 lb bags	Toronto	$5 to 6 per cwt
Lime, hydrated	100 lb bags	Beachville	$20 per ton
Nalcolyte 110	25 lb bags	Burlington	$52.80 per cwt
Separan NP-10	50 lb bags	Midland, Mich.	$160 to 200 US per cwt.
Soda Ash	100 lb bags	Amherstburg	$2.15 per cwt.
Sodium Aluminate	50 lb bags	Burlington	$21.20 per cwt.
Sodium Hydroxide	100 lb or 425 lb drum	Toronto	$8 to $10 per cwt

*Activated Silica is produced by the reaction between 'N' Silicate and one of the above chemicals.

Note: All the prices are estimates only and quoted for orders of one ton or greater. They are intended to be used only as a guide in this study. They do not include any sales tax nor any transportation costs.

TABLE 13

GENERAL FREIGHT RATES VIA CANADIAN PACIFIC RAILWAY

	To Haileybury from	
Weight	Toronto	Montreal
up to 24,000 lb	$0.68 per cwt.	$0.87 per cwt.
30,000	0.56	0.73
40,000	0.46	0.61
50,000	0.43	0.58

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